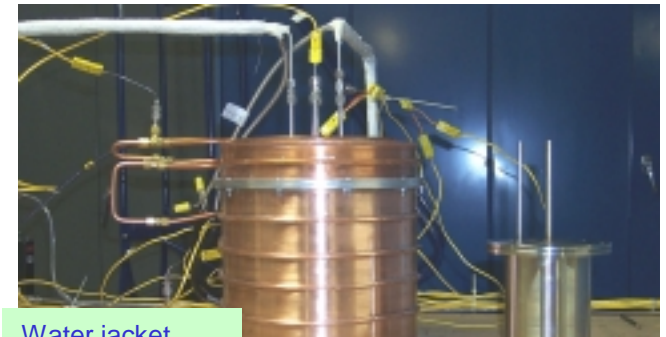


# Progress in IFE Technology: July - October 2000

## Safety and Environment:

*D. A. Petti, B. J. Merrill and R. L. Moore*—Idaho National Engineering and Environmental Laboratory

- Supporting ARIES-IFE effort as well as LLNL IFE colleagues on IFE safety analyses.
- Completed tantalum (T222 alloy) mobilization experiments (potential IFE hohlraum material)—observed significant spalling but very little volatilization.
- Molten salt safety experiments:
  - Completed construction of first pots for Flibe experiments.
  - Unirradiated mobilization pots built; thermal shakedown tests complete.
  - Interim design of irradiation version (FLIQUIRE) is complete. Detailed shielding design to be completed FY01.
  - Unirradiated Flibe mobilization test with air and steam in FY01.



Water jacket  
surrounding  
heater assembly

One liter Flibe pot (10  
cm ID, 17 cm high)

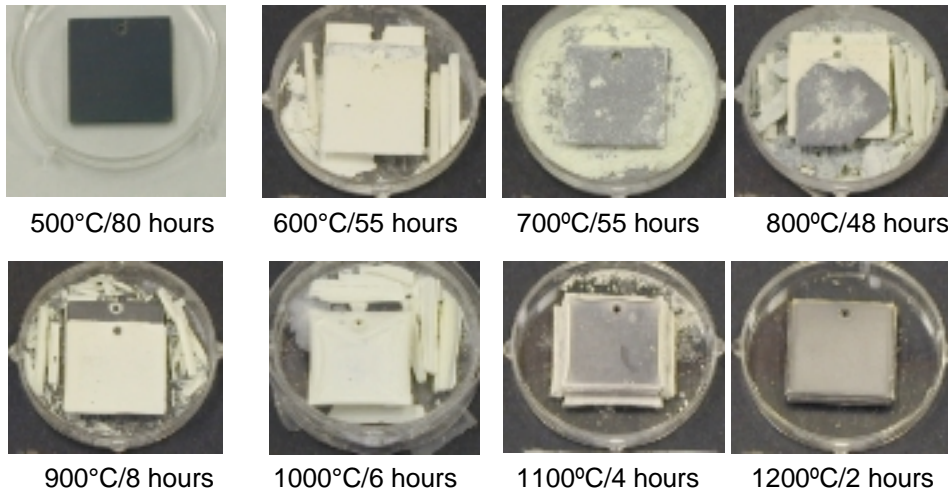
## Flibe Molten Salt Safety Experiment

### Publications and Presentations:

G. R. Smolik, D. A. Petti, and S. T. Schuetz, "Oxidation and Volatilization from Tantalum Alloy During Air Exposure," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

J. W. Sterbentz, J. E. O'Brien, R. A. Anderl, G. R. Smolik, D. A. Petti, and K. A. McCarthy, "Design of the FLIQUIRE Experiment," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

J. P. Sharpe, W. J. Carmack, and D. A. Petti, "Characterization of Dust and Debris Collected from the Nova Facility," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.



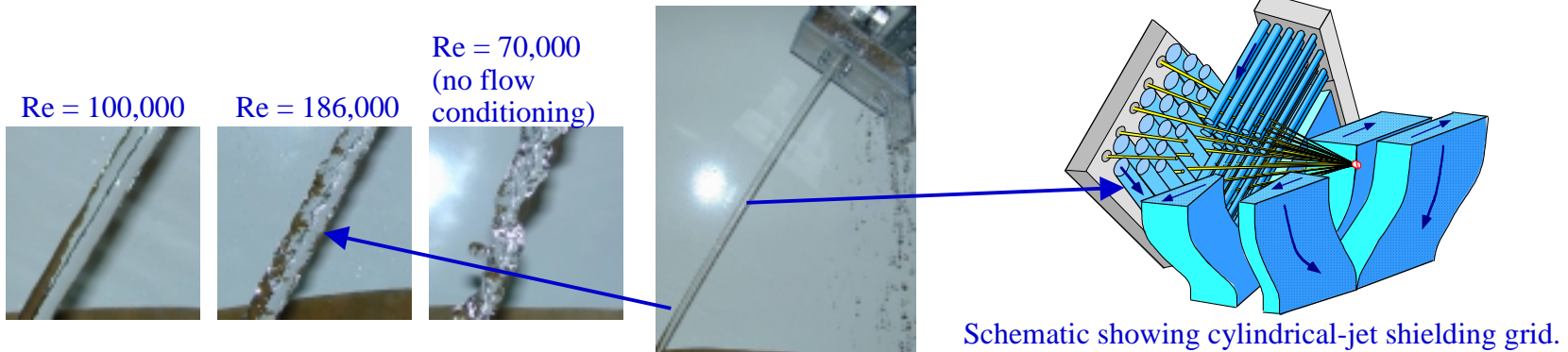
## Samples from Tantalum Mobilization Experiments

# Progress in IFE Technology: July - October 2000, (Cont'd.)

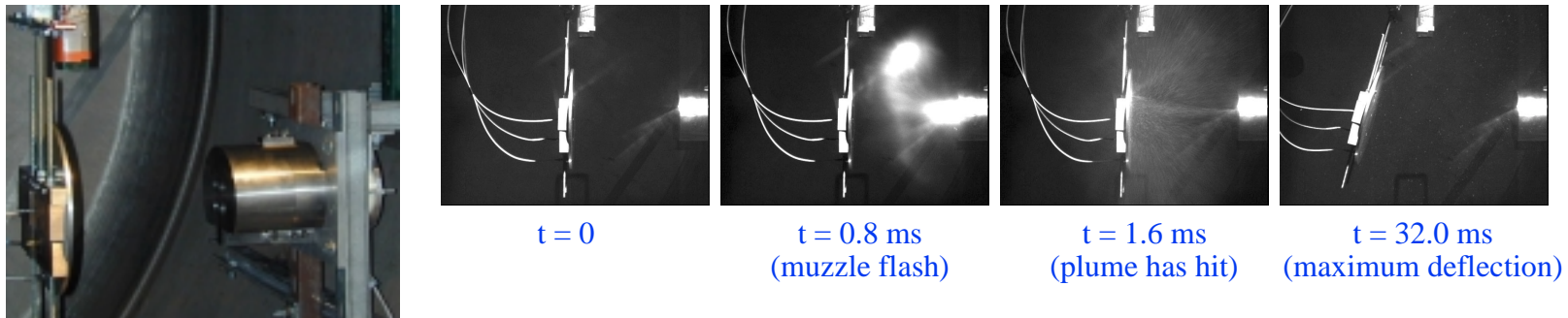
## Thick-Liquid Protection:

P. F. Peterson, S. Pemberton, C. Debonnel, C. Jantzen, R. Abbott—University of California at Berkeley

- UC Berkeley completed design, fabrication and testing of cylindrical jet nozzles capable of creating smooth, high velocity cylindrical liquid jets, matching those required for use in beam-line shielding grids for heavy-ion fusion.



- UC Berkeley completed calibration tests of a four-cartridge firing device for studying thick-liquid pocket response to IFE target disruptions in scaled water experiments. The calibration tests, measuring deflection of a pendulum-mounted disk, showed that the mechanism can deliver rapid impulse loads exceeding 150 Pa sec (60 Pa sec is required for 1/4 scale liquid response tests).



## Publications and Presentations:

“Partial-Pocket Experiments for IFE Thick-Liquid Pocket Disruption and Clearing,” Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

“Design Methods for Thick-Liquid Protection of Inertial Fusion Chambers,” Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

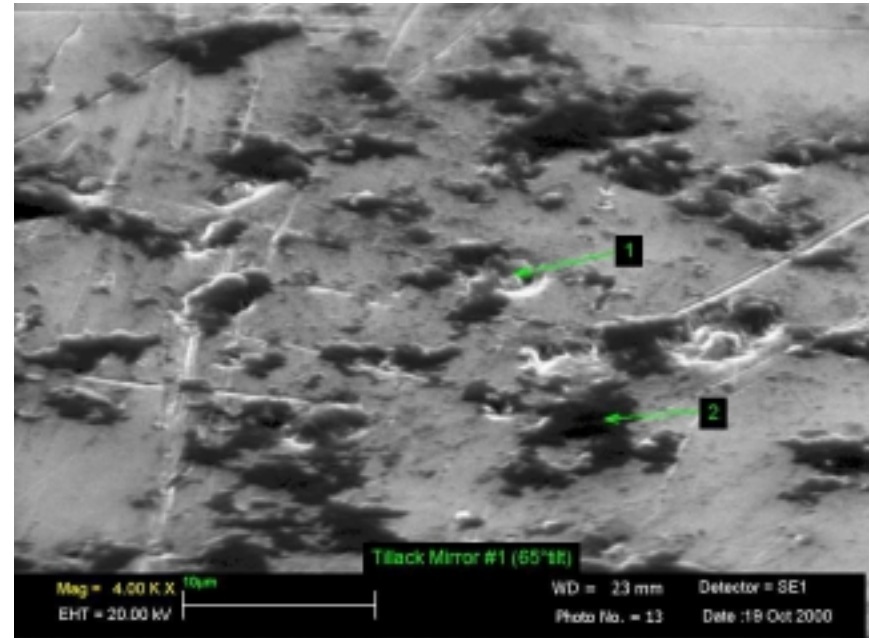
“Cylindrical Liquid Jet Grids for Beam-Port Protection of Thick-Liquid Heavy-Ion Fusion Target Chambers” Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

# *Progress in IFE Technology: July - October 2000, (Cont'd.)*

## Laser Interactions and Final Optics Studies:

M. S. Tillack, F. Najmabadi, M. Zaghloul—University of California at San Diego (see web site at <http://aries.ucsd.edu/IFE/> )

- Laser damage to the 1" round Al mirrors was obtained at  $0.2 \text{ J/cm}^2$  fluence and normal incidence. The post-test surface analysis (see figure) strongly suggests that sub-micron occlusions in the initial surface (arising from impurities in the Al alloy) led to melting. Future tests will be carried out with ultra-pure diamond-turned Al and sputter-coated surfaces in order to further explore the mechanisms of damage.
- Auger electron spectroscopy was used to measure the natural oxide thickness of  $\sim 10 \text{ nm}$  on diamond-turned Al mirrors.
- A 4-layer Fresnel model was developed for scoping of reflectance of multi-layer surfaces. All 4 layers can have arbitrary complex refractive index. The model is being used to study coated and contaminated substrates.
- Long rectangular mirrors were fabricated by diamond turning. The dimensions are  $1.5 \times 15.0 \text{ cm}$ . Initial low-fluence testing at incidence angles above  $85^\circ$  showed unexpected beam profile distortions, including interference patterns. Further examination of optical distortions are being undertaken at low fluence before damage tests are initiated.
- A mini-workshop on final optics damage modeling and testing was held on Nov. 8 at UCSD with participants from UCLA and UCSD.
- Experiments on propagation and breakdown threshold of gases under intense laser irradiation are planned to begin in Jan. 2001. The experiment design is completed and the equipment (a vacuum tank, associated vacuum system and gas valves, optics and diagnostics) has been ordered.



**SEM photo of damaged Al mirror at 4000× magnification**

## Publications and Presentations:

M. S. Tillack, F. Najmabadi, L. A. El-Guebaly, D. Goodin, W. R. Meier, R. R. Peterson, D. A. Petti, K. R. Schultz, L. M. Waganer, and the ARIES Team, "ARIES Inertial Fusion Chamber Assessment," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

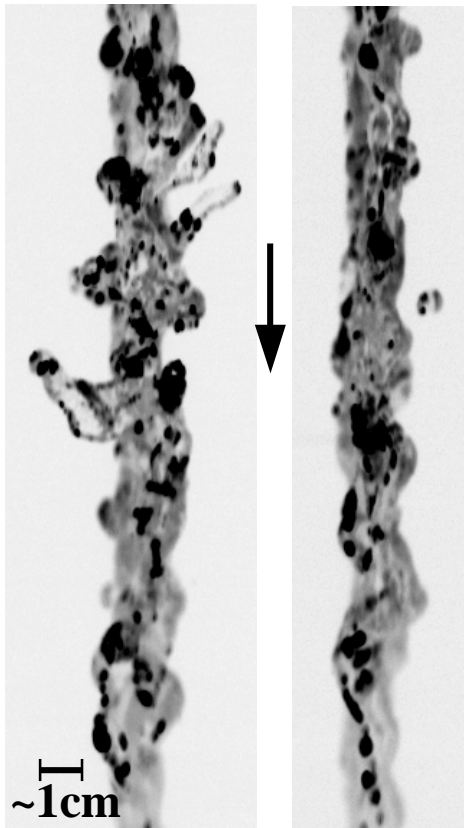
M. S. Tillack, "Damage-resistant optics research for IFE," Laser-IFE Final Optics Mini-Workshop, 8 Nov. 2000.

# Progress in IFE Technology: July - October 2000, (Cont'd.)

## Thick-Liquid Protection:

J. A. Collins, D. Sadowski, M. Yoda and S. I. Abdel-Khalik—Georgia Institute of Technology

- Reconfigured Georgia Tech. Liquid Sheets Facility for higher Re, We:
  - Currently studying sheets at  $Re \approx 80,000$ ;  $We \approx 8500$
  - Already seeing sheet breakup and droplet formation at these relatively low We
  - Facility capable of producing sheets at  $Re \approx 150,000$ ,  $We \approx 30,000$



4 ms “Snapshots” of Sheet

## *Snapshots reveal droplet formation from liquid sheets:*

- Experiment used water into air at  $P_{atm}$
- $Re = 8 \times 10^4$ ;  $We = 8500$
- $x/\delta = 60-85$  (HYLIFE  $x/\delta < 30$ )
- Droplets shown on the right; pre-droplet ligaments visible on the left
- Droplets at lower  $x/\delta$  for higher  $We$ ; HYLIFE  $We = 10^5$

» Droplet formation major issue for HYLIFE-II?

## Publications and Presentations:

W. Meier, M. Abdou, G. Kulcinski, R. Moir, A. Nobile, P. Peterson, D. Petti, K. Schultz, M. Tillack, and M. Yoda, “Overview of IFE Chamber and Target Technologies R&D in the U.S.,” 18th International Atomic Energy Agency Fusion Energy Conference, Sorrento, Italy (Sep. 2000).

J. A. Collins, M. Yoda, and S. I. Abdel-Khalik, “Direct measurements of free-surface smoothness in turbulent liquid sheets,” Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

L. C. Elwell, D. L. Sadowski, M. Yoda, and S. I. Abdel-Khalik, “Dynamics of oscillating turbulent liquid sheets,” Ibid.



# Progress in IFE Technology: July - October 2000, (Cont'd.)

## Thick-Liquid Protection:

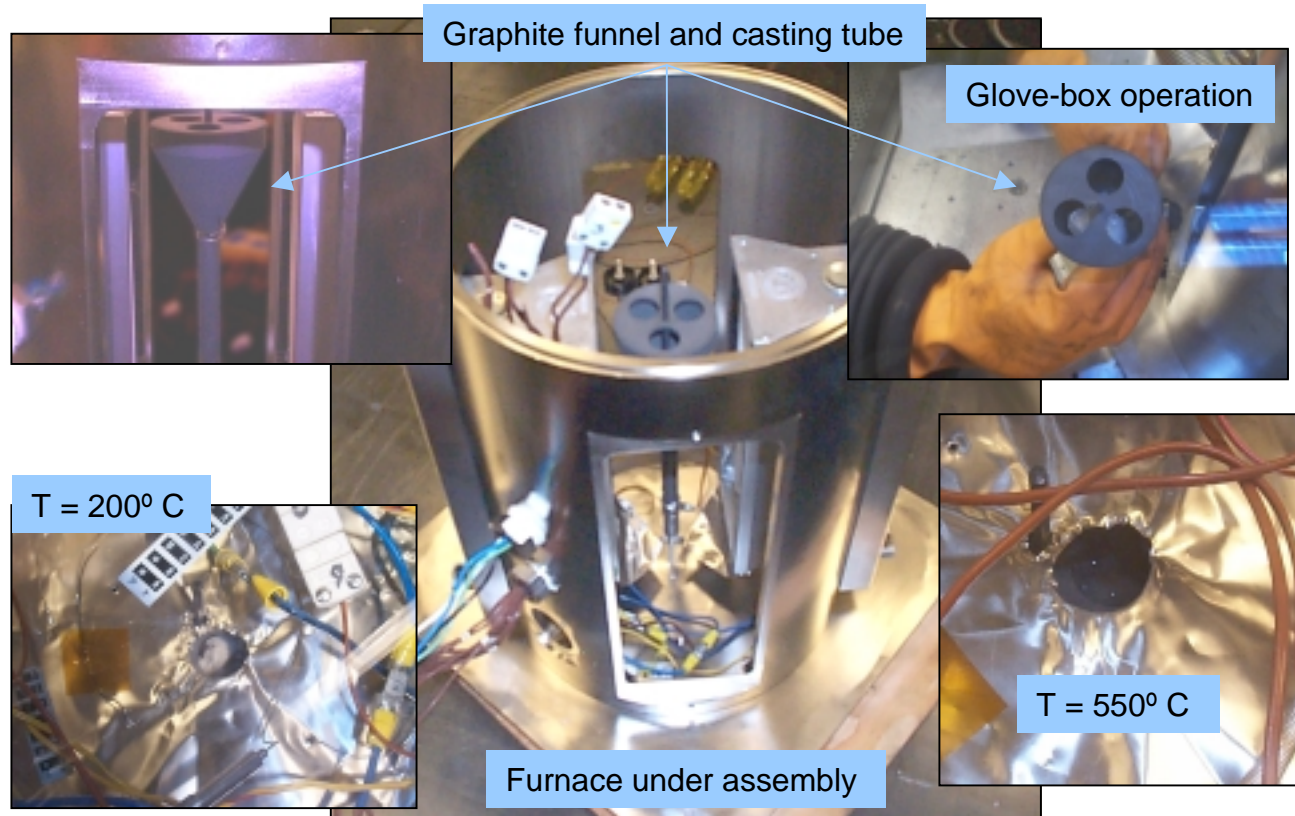
N. B. Morley, A. Y. Ying and M. Abdou—University of California at Los Angeles (see web site at [www.fusion.ucla.edu/IFE](http://www.fusion.ucla.edu/IFE))

- Flibe Vapor Condensation Experiment:
  - Successfully obtained the first set of shots using a Flibe liner in the plasma source.
  - Low energy, non destructive shots confirmed the expected capability for Flibe vapor generation.
- Flibe Casting:
  - A vacuum furnace for Flibe melting and casting has been built. The furnace frame is nickel-plated aluminum. A secondary enclosure of ceramic radiative heaters and reflectors ensures a uniform and time controlled temperature history in the furnace core. Flibe is in contact with high-graded graphite.
  - The furnace itself and all operations with Flibe are handled inside a beryllium safe glove-box.

## Publications and Presentations:

P. Calderoni, A.Y. Ying, T.A. Sketcheley, M. Abdou "Description of a Facility for Vapor Clearing Rates Studies of IFE Reactors FLiBe Liquid Chambers," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

S. Quan, N. B. Morley and M. Abdou "Exploration of the "damage limit" light flux for grazing incidence liquid metal mirrors," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

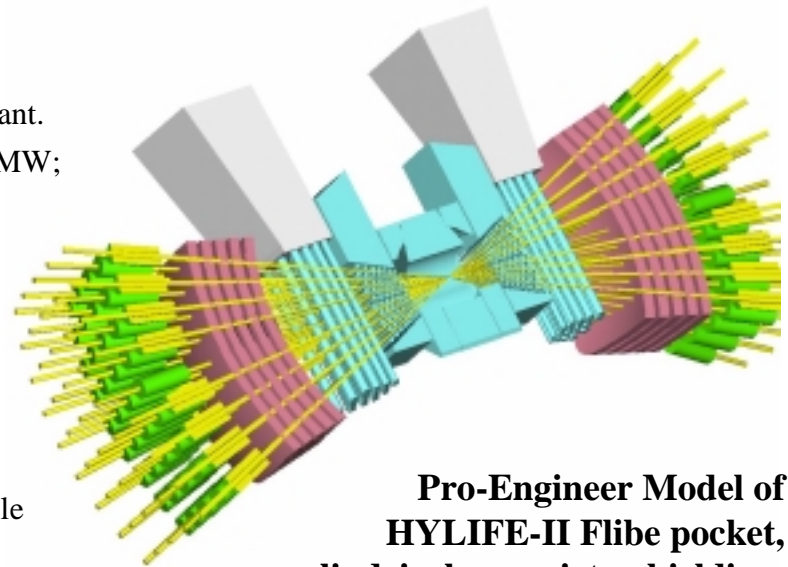


## *Progress in IFE Technology: July - October 2000, (Cont'd.)*

### Integration, Safety & Environment, Final Focus Magnet Shielding:

*W. R. Meier, J. F. Latkowski, R. W. Moir, S. Reyes, and H. K. Springer*—Lawrence Livermore National Laboratory

- Completed loss-of-coolant/vacuum and loss-of-flow/vacuum accident analyses for HYLIFE-II and Sombrero IFE power plant designs, respectively:
  - HYLIFE-II analysis utilized new version of MELCOR (developed by INEEL) code including Flibe as a working fluid.
  - HYLIFE-II results suggest that public evacuation plan can be avoided—site boundary accident dose is 5.0 mSv (0.50 rem) for average weather conditions.
  - Sombrero findings include: (1) need to remove radionuclides from chamber fill gas, (2) need for further study of carbon composite oxidation, and (3) need for further study of tritium retention in irradiated carbon composites.
  - Sombrero results suggest additional work is needed—site boundary accident doses range from 56 mSv (5.6 rem) with untreated Xe chamber fill gas to 12 mSv (1.2 rem) with Xe that is treated; Use of Kr fill gas reduces the dose to 11 mSv (1.1 rem).
- Scaling study for a heavy ion Engineering Test Facility (ETF) completed between LLNL and UCB:
  - Economics drives chamber design to 30-40% of that for a power plant.
  - $E_{\text{driver}} \sim 2 \text{ MJ}$ , Yield  $\sim 30 \text{ MJ}$ , repetition rate  $\sim 10 \text{ Hz} \rightarrow P_{\text{fus}} = 285 \text{ MW}$ ;  
 $P_{\text{th}} = 335 \text{ MW}$ ; could deliver nearly  $80 \text{ MW}_e$  to grid.
  - Beam would need to be focused to  $< 1.4 \text{ mm}$ .
  - Target production would need to be faster and more precise than for a power plant.
- Three-dimensional heavy ion final focus magnet shielding calculations completed:
  - Discrete rectangular slabs or cylindrical cross jets provide acceptable shielding.
  - Last set of magnets would survive for lifetime of power plant.
  - Neutron activation, radioactive waste, and magnet cooling issues need additional work.



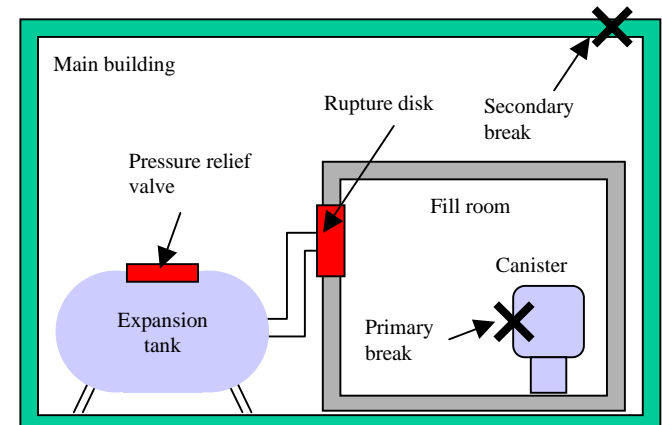
**Pro-Engineer Model of  
HYLIFE-II Flibe pocket,  
cylindrical cross-jets, shielding,  
and final focus magnets.**

# *Progress in IFE Technology: July - October 2000, (Cont'd.)*

## Integration, Safety & Environment, Final Focus Magnet Shielding, (Cont'd.):

W. R. Meier, J. F. Latkowski, R. W. Moir, S. Reyes, and H. K. Springer—Lawrence Livermore National Laboratory

- Tritium inventory estimated and accident analysis completed for conceptual target fabrication facility:
  - Target fill time is key parameter in plant tritium inventory; materials able to withstand higher pressure differentials and/or temperatures are needed.
  - Huge leverage for cold assembly (capsules first filled and then assembled inside hohlraums at cryogenic temperatures).
  - Low burn-up fraction targets (e.g., those with DT ablaters) stress the tritium processing system and fabrication facility.
  - List of acceptable high-Z target materials expanded; chemistry of high-Z particulates needs to be studied.



**Schematic of MELCOR Model used for Target Fabrication Safety Calculations**

## Publications and Presentations:

J. F. Latkowski and W. R. Meier, "Heavy-Ion Fusion Final Focus Magnet Shielding Designs," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

J. F. Latkowski, S. Reyes, G. E. Besenbruch, and D. T. Goodin, "Preliminary Safety Assessment for an IFE Target Fabrication Facility," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

W. R. Meier, D. A. Callahan-Miller, J. F. Latkowski, B. G. Logan, J. D. Lindl, and P. F. Peterson, "An Engineering Test Facility for Heavy Ion Fusion—Options and Scaling," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

R. W. Moir, "Final optics protection in laser inertial fusion with cryogenic liquid droplets," LLNL, UCRL-ID-140559 (Aug. 2000).

R. W. Moir, "Liquid walls for fusion reaction chambers," LLNL, UCRL-JC-135743 (Sep. 1999) and *Comments on Plasma Physics and Controlled Fusion* 2 (2000) 99-111.

S. Reyes, J. F. Latkowski, J. Gomez del Rio, and J. Sanz, "Accident Doses Analysis of the Sombrero Inertial Fusion Energy Power Plant Design," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*. *Recipient of the Conference Best Student Paper Award.*

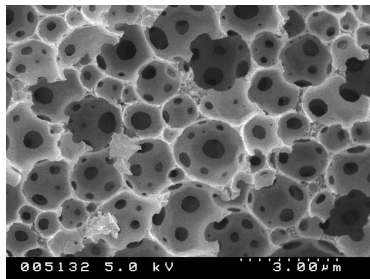
S. Reyes, J. F. Latkowski, J. Gomez del Rio, and J. Sanz, "Progress in Accident Analysis of the HYLIFE-II Inertial Fusion Energy Power Plant Design," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

# *Progress in IFE Technology: July - October 2000, (Cont'd.)*

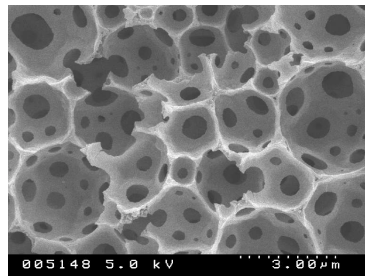
## Target Fabrication, Injection and Tracking:

*D. Goodin, A. Nobile, R. Petzoldt, P. Gobby, W. Steckle, M. Tillack, A. Newkirk, M. Cherry—GA, UCSD, LANL*

- Potential target filling and assembly processes were evaluated. The tritium inventory for the fabrication facility is highly dependent on the process selected.
- The initial feasibility of fabricating low density metallic doped organic foams for indirect drive targets by doping hydrocarbon foams was demonstrated. Major morphology changes due to the doping process did not occur.
- The Conceptual Design Review for the experimental target injection and tracking system was successfully completed.
- Gas leakage and preliminary release testing was conducted for a prototype direct drive target injection sabot. A video of the sabot separation sequence can be found on the web at <http://aries.ucsd.edu/ARIES/WDOCS/IFE/sabot.html>.
- DSMC modeling of drag on a direct drive target during injection predicts a significant effect on the target trajectory from small variations in the gas density, possibly requiring in-chamber tracking.

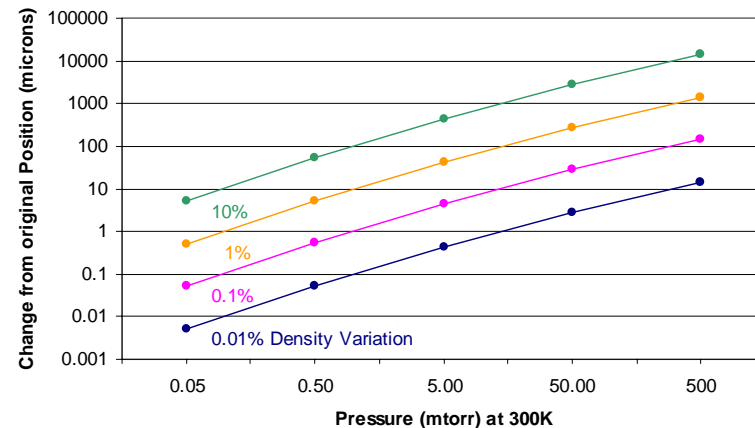


**Before Doping**



**After Doping**

*Polystyrene foam for metallic doping*



*Calculated effects of gas pressure variability on a direct drive target trajectory during injection*

## Publications and Presentations:

D. T. Goodin et al, "IFE Target Fabrication Plans and Progress," Presented at the ARIES Project Meeting, PPPL (Sep. 2000).

D. T. Goodin et al, "Target Injection into a Gas-Filled Chamber," Presented at the ARIES Project Meeting, PPPL (Sep. 2000).

R. Petzoldt et al, "Design of the Target Injection and Tracking Experimental System," Presented at the ARIES Project Meeting, PPPL (Sep. 2000).

P. Gobby et al, "Concepts for Fabrication of Inertial Fusion Energy Targets," Presented at the ARIES Project Meeting, PPPL (Sep. 2000).

R. Petzoldt et al, "Design of an Inertial Fusion Energy Target Tracking and Position Prediction System," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.

A. Nobile et al, "Concepts for Fabrication of Targets for a Heavy Ion Driven Inertial Fusion Energy Plant," Presented at the 14th ANS Topical Meeting on the Technology of Fusion Energy, Park City, Utah (Oct. 2000), and to be published in *Fusion Technology*.